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Laboratory Evaluation of Moisture Cure Urethane Coatings

Alfred D. Beitelman

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Final Report

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Under Work Unit #33285

ABSTRACT: The Corps of Engineers is considering the use of moisture cure urethane paints on navigation and other hydraulic structures. Since it is desirable to specify paints generically, work was initiated to determine the salient properties of commercially available products from four manufacturers. Testing included short-term bench tests on the liquid materials as well as long-term exposure testing of coated panels in sea salt immersion, freshwater immersion, atmospheric exposure, and accelerated weathering conditions. The results showed significant performance differences among similar products from alternate manufacturers.

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Preface

Headquarters, U.S. Army Corps of Engineers (HQUSACE), authorized the study described in this report as part of the High-Performance Materials and Systems (HPM&S) Research Program. The work was performed under Work Unit 33285, "Environmentally Acceptable Paints and Coatings," for which Mr. Alfred D. Beitelman, Construction Engineering Research Laboratory (CERL), was the Principal Investigator. Messrs. Andy Wu and M.K. Lee, HQUSACE, were the HPM&S Program Monitors. Program Manager for HPM&S was Dr. William P. Grogan, Geotechnical and Structures Laboratory (GSL).

The initial screening tests and panel preparation were performed by Corrosion Control Consultants and Labs of Kentwood, MI, under contract to CERL's Materials and Structures Branch (CF-M), Facilities Division (CF). Long-term exposure testing and panel evaluations were performed at the CERL Paint Technology Center by J. Lake Lattimore.

Dr. Paul Howdyshell is Acting Chief, CF-M, and L. Michael Golish is Chief, CF. The Director of CERL is Dr. Alan W. Moore; Acting Director of GSL is Dr. David W. Pittman. CERL and GSL are elements of the Engineer Research and Development Center (ERDC), U.S. Army Corps of Engineers. Commander and Executive Director of ERDC is COL James R. Rowan, EN. Dr. James R. Houston is ERDC Director.

1 Introduction

Background

Paint systems based on the moisture cure urethane (MCU) resin have been available commercially for over 20 years. The resin is combined with various pigments to produce zinc-rich primers, tar-filled coatings, as well as colored mid-coats and topcoats. One of the common pigments used in conjunction with MCU is micaceous iron oxide (MIO). This iron oxide pigment in a flake form is reported to provide superior corrosion resistance and water resistance properties.

Although the paints have been available for many years, there are no known studies comparing the performance of the products produced by various manufacturers nor have there been any industry specifications on which to base comparative studies. The Society for Protective Coatings (SSPC) is in the process of developing standards for MCU products and systems. Research was needed to determine if commercially available products will meet the proposed SSPC requirements and how well these products may perform on Corps of Engineers civil works projects.

Objective

The objective of this program was to conduct laboratory evaluations on commercially available MCU paints. Results of this study will be used to develop industry specifications and determine potential use of the coatings on Corps of Engineers structures.

Approach

Product lines from all known MCU paint manufacturers were reviewed for comparable products. Four manufacturers were selected as marketers of a full range of products. Nine similar products were selected from each manufacturer. The products were tested for basic properties according to a draft SSPC specification and applied to laboratory panels for long-term performance studies.

Scope

This research consists of an evaluation of a limited number of commercially available MCU paints. Evaluations include the tests detailed in a draft SSPC specification as well as a number of long-term exposure tests.

Mode of Technology Transfer

Information contained in this report will be used as a basis for developing industry or government specifications for MCU paints and coatings. The information will also be used for future updates of Engineering Manual (EM) 1110-2-3400, "Painting: New Construction and Maintenance" and Unified Facilities Guide Specification 09965, "Painting: Hydraulic Structures." Information will also be presented in Proponent Sponsored Engineer Corps Training (PROSPECT) paint courses.

2 Test Procedures

Selection of Products

Product lines from all known MCU paint manufacturers were reviewed for comparable products. Products included:

- zinc primer
- zinc/MIO primer
- accelerator
- MIO midcoat
- MIO topcoat
- coal tar topcoat
- aluminum topcoat
- gloss topcoat.

Consideration was given to product type but not to manufacturer's suggested use guidance. In some cases, this meant products were subjected to test conditions more severe than recommended by the manufacturer. Manufacturers not marketing all products were removed from consideration. From the remaining manufacturers, four were selected: Sherwin-Williams, Tnemec, Wasser, and Xymax.

Preparation of Test Panels

Preparation of Panels for Salt Fog Testing of Primers

Panels used for this test were American Society for Testing and Materials (ASTM) A36 steel with dimensions 4 in. x 6 in. x 1/8 in. (100 mm x 150 mm x 3.2

mm). The test panels were blast cleaned in accordance with SSPC-SP5*. Blasting produced an angular anchor profile of 63 ± 25 (2.5 ± 1.0 mil) as measured in accordance with ASTM D4417, Method C. The primers were spray applied according to manufacturer's recommendations to a nominal dry film thickness of 2.5-3.5 mils. Prior to any exposure testing, all panels were aged for 14 days at 24-26 °C and 45 to 55 percent relative humidity. The film thickness was measured with ASTM D1186 using a PosiTector 6000 gage (DeFelsko Corp., Ogdensburg, NY). The panels were scribed with an "X" according to the requirements of ASTM B117.

Preparation of Panels for System Exposure Testing

Steel test panels were ASTM A607 grade 50. Dimensions for the Salt Fog/Ultraviolet (UV)-Condensation test were 3 in. x 6 in. x 1/8 in. (75 mm x 150 mm x 3.2 mm). Dimensions for the Atmospheric Exposure, Substitute Oceanwater Immersion, and Freshwater Immersion tests were 3 in. x 9 in. x 1/8 in. (75 mm x 230 mm x 3.2 mm). Panels were cleaned with solvents in accordance with SSPC-SP1 prior to blast cleaning. The test panels were blast cleaned in accordance with SSPC-SP10. Blasting produced an angular anchor profile of 63 ± 25 (2.5 ± 1.0 mil) as measured in accordance with ASTM D4417, Method C. Coatings were spray applied according to Section 5.3 of the SSPC draft Specifications (shown following test results given in Appendices A – H). The thickness of the paint was applied in compliance with the same draft Specifications, Section 5.4. The film thickness of each coat was measured according to ASTM D1186 using a PosiTector 6000 gage.

Test Performance and Requirements

The following eight tests were performed on individual paints:

Pot Life

Paints were mixed in accordance with manufacturer's recommendations and allowed to stand for 4 hours at 2 °C and 50 percent relative humidity. The paint

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* All standards referenced in this report are listed beginning on p 13.

was then observed for any change in physical properties and the Adhesion test was performed. Any change in physical properties or adhesion was noted.

Working Properties

Each paint was mixed and spray applied in accordance with Federal Standard (FED-STD)-141, Methods 4331 and 4541.

Mudcracking

The dried coating was observed under 10X magnification for evidence of mudcracking. Coating thickness was recorded.

Adhesion

The coating adhesion was tested in accordance with ASTM D3359, Method B "Cross-Cut/Tape Test."

Salt Fog Resistance

All zinc-containing primers were tested in accordance with specification ASTM B117 and evaluated according to the requirements of SSPC Paint 20, paragraph 5.9.

Total Solids

This test was done according to ASTM 2369.

Pigment

This test was done according to ASTM 2371.

Polyisocyanate (NCO) Content

This test was done according to the SSPC Draft Polyurethane System Specification. (Test requirements are attached at Appendix I.)

The following tests were performed on multi-coat paint systems:

Atmospheric Exposure

This test was done in compliance with ASTM D1014. The panels were exposed in Champaign, IL, at 45°, facing south, and insulated in accordance to ASTM D4141.

Tap Water Immersion

Panels were submerged in potable water in a cold-water tank. The panels were hung on a steel pole insulated with a plastic tube and suspended across the tank. The panels were submerged in the water so that the water was at the height just below the hole in the top of the panel. The water was kept at 24 ˚C with a consent flow of water. Each panel had one 2 in. (5 cm) scribe line at a 45^{o} angle on the face of the coated panels. The criteria used to evaluate these panels were ASTM standards D610, D659, and D714.

Substitute Oceanwater Immersion

A sea salt solution was mixed according to ASTM D1141. Each panel had a single 2 in. (5 cm) scribe at a 45^{o} angle on the face of the coated panels. The panels were hung with wire on an insulated bar suspended on top of the tank. The length of an insulated hanger was adjusted so that a waterline was created 3/4 in. (2 cm) below the top of the panel. The solution was maintained at 24 ˚C for the duration of the test. The criteria for evaluating the panels were ASTM Standards D610, D659, and D714.

Accelerated Weathering

Testing was done in compliance with ASTM D5894 using the following conditions:

The UV-Condensation apparatus was an Atlas Model 1072241 manufactured by the Atlas Electric Devices Co., Chicago, IL. The operating cycle was 4 h UV/60 ˚C followed by 4 h CON/50 ˚C where UV is ultraviolet light (lamps) only, and CON is condensation conditions only. The Salt Spray apparatus was a Q Fog Prohesion / Salt Spray chamber Model SF/MP450 manufactured by the Q-Panel Company, Cleveland, OH. The electrolyte solution was 0.05 percent sodium chloride and 0.035 percent ammonium sulfate by weight. The panels were transferred after 1 week of exposure in each cycle.

The panels were scribed according to the procedure described in ASTM D1654. Two parallel lines on the face of the coated panels to expose the underlying metal before testing. The lines were at least 0.5 in. (1.3 cm) from the edge, the top, and the bottom of each panel and at least 2.0 in. (5.0 cm) from each other. Each scribe was at least 2.4 in. (6.1 cm) long and ran vertically on the face of the panel.

3 Test Results

Salt Fog/UV Condensation Test

The panels in the Salt Fog/UV Condensation test were evaluated at 2,000, 3,000, 4,000, 7,000, and 10,000 hours. The undercut values for duplicate panels are averaged and shown in Appendix A. The results clearly show that all Xymax systems performed the poorest in this high humidity test. In every comparable system the Xymax panels have the lowest rating after 10,000 hours, with many of the panels having the lowest rating as early as 2,000 hours.

In all cases, Wasser panels with the pure zinc (without MIO) primers either provided the best performance or tied with the corresponding Sherwin Williams system. These Wasser systems were also superior to the Wasser systems having the same topcoat but with the MIO zinc primer.

While the Wasser pure zinc primer provided better performance than their zinc primer with MIO, the opposite was true for the Sherwin Williams and Tnemec primers.

Comparing the coal tar topcoated zinc with and without the accelerator, it is noted that the accelerator may have had a minor detrimental effect on the Xymax and Sherwin Williams systems, while the Wasser and Tnemec systems showed significant improvement.

All Tnemec panels having two coal tar topcoats exhibited delamination between the midcoat and final coat. No other coating systems exhibited this mode of failure. The failure was actually noted within days after initiation of the Salt Fog/UV Condensation test and was also noted on all other exposures shortly after beginning the respective tests. This delamination may have hidden the initial rust undercutting resulting in perfect blister ratings for the 2,000- and 3,000-hour observations.

Substitute Oceanwater Immersion

The results for the 5,000- and 10,000-hour substitute oceanwater immersion test are shown in Appendix B. At 5,000 hours, each panel was casually examined for undercutting at the scribe, blistering, rusting, and any other notable changes in appearance. All of the scores were rusting. None of the panels showed undercuts and only the Tnemec panels with coal tar topcoats had any loss of intercoat adhesion. Blistering had begun on many of the panels. In some cases, the blistering was localized near the edges or scores of the panels; in other cases, it was common on the entire submerged area of the panels. Formal ASTM blister ratings were conducted on the panels after 10,000 hours of immersion.

In all cases, Wasser panels with the pure zinc (without MIO) primers provided the best performance, having no notable defects after the exposure period. The Tnemec MIO zinc systems, except those with coal tar topcoats, also provided excellent performance. All Tnemec panels having two coal tar topcoats exhibited delamination between the midcoat and final coat. All Xymax systems exhibited extensive blistering; those with MIO zinc primer having either larger or more dense blistering than those without MIO. Some of the individual blisters on the Xymax panels were more than 2.5 cm (1 in.) in diameter. Performance among the Sherwin Williams systems varied greatly. Systems with aluminum topcoats provided the best performance, while all systems with coal tar topcoats had very large blisters, including some as large as 2.5 cm (1 in.) in diameter. The only Sherwin Williams system without defect had the MIO zinc primer and aluminum topcoats.

Comparing the coal tar topcoated zinc with and without the accelerator, it is noted that there is no difference with the Wasser panels; however, the trend in all other systems is for either larger or denser blisters on systems where the accelerator was used.

Freshwater Immersion

The results for the 5,000- and 10,000-hour freshwater immersion test are shown in Appendix C. At 5,000 hours, each panel was casually examined for undercutting at the scribe, blistering, rusting, and any other notable changes in appearance. All of the scores were rusting. None of the panels showed undercuts, and only the Tnemec panels with coal tar topcoats had any loss of intercoat adhesion. Blistering had begun on many of the panels. In some cases, the blistering was localized near the edges or scores of the panels; in other cases, it was common on the entire submerged area of the panels. Formal ASTM blister ratings were conducted on the panels after 10,000 hours of immersion.

Comparing the freshwater data to the oceanwater data shows that the environments result in similar system performance trends; however, the fresh water is generally less aggressive. The Wasser systems with coal tar topcoats outperformed all other coal tar systems. The Wasser systems with MIO zinc primer, MIO intermediate and either MIO or gloss topcoats were among the poorest performing systems having blisters that were even larger than on their oceanwater panels. All Sherwin Williams panels with coal tar topcoats had large blisters associated with edges and all Tnemec panels with coal tar had delamination between the tar topcoat and the tar intermediate coat. Tnemec and Sherwin Williams systems without coal tar all provided excellent performance.

Atmospheric Exposure

Test chalking results for the atmospheric exposure test are shown in Appendix D. The panels were evaluated for rust, undercutting, chalking, and blistering. The score on all panels had initial rust by 5,000 hours, but no additional coating deterioration associated with the scores was noted at the 10,000-hour evaluation. At 5,000 hours, chalking was visible on all of the manufacturers' panels having coal tar topcoats, but Tnemec also had loss of intercoat adhesion on these same panels. Chalking was also visible on the Sherwin Williams panels with MIO topcoat. At 10,000 hours, all panels having aluminum topcoats as well as the Tnemec panels with gloss topcoat had visible chalk.

Total Solids, Pigment, and NCO Content

When comparing the composition of the products from the four manufacturers, it was noted that the total solids, pigment percent, and NCO content are very similar for most of the corresponding products. All of the zinc primers met the requirements of SSPC Paint 20 (organic) (see Appendix E). All of the products met the resin and application requirements of the SSPC draft specification for Single Component Moisture Cure Weatherable Aliphatic Polyurethane Topcoat, Performance-Based (see Appendix I). The color change and gloss change tests of this specification were not performed due to equipment limitations. Many difficulties were encountered in performing the NCO content test largely due to atmospheric moisture coming into contact with the paint during the test.

4 Conclusions and Recommendations

Standard (pure) zinc primers were evaluated both with and without an accelerator. It cannot be stated universally that the accelerator adds to or detracts from the performance of the primer. In the salt fog/UV test, the two best performing systems both used the accelerator, which resulted in significant increases in performance. In other tests and with other manufacturers' products, the results indicate little to no discernable impact from the use of the accelerator.

Standard (pure) zinc primers were compared to zinc primers containing MIO. This primer variation was used as the primer for a number of different topcoats. With Wasser systems, it is clear that the standard zinc primer results in systems with superior rust undercutting resistance in accelerated salt fog/UV exposures as well as in blister resistance when immersed in ocean or fresh water. Although such a clear superiority is not evident with the primers from the other manufacturers, there appeared to be a trend favoring the MIO zinc primer from Sherwin Williams and Tnemec. The performance of Xymax systems varied so that no conclusions could be drawn.

The Corps of Engineers uses epoxy zinc/epoxy coal tar systems extensively in some of the aggressive exposures including ocean water, fresh water, sewage systems, and buried structures. With this type of use in mind, comparable MCU systems having MCU zinc primers followed by two coats of MCU coal tar were evaluated. All Tnemec exposure panels experienced delamination between the two coal tar coats. No other instance of delamination was noted with any system from any manufacturer in the entire test series. Only the Wasser system applied over their standard zinc primer performed for 10,000 hours in immersion in both fresh and ocean water without any blistering. Both Sherwin Williams and Tnemec zinc/coal tar systems had large blisters over the entire panel surfaces on the oceanwater panels. All Xymax coal tar systems had smaller blisters over the entire oceanwater immersed surface with large blisters near scores and edges. The extent of the failures of Sherwin Williams, Tnemec, and Xymax coal tar systems suggests they should not be specified for use where the environment includes immersion. Only the Wasser system with the standard zinc has the potential to replace the currently used epoxy system. It is interesting to note that the

Wasser coal tar system is not the highest performing system among those tested. Other Wasser systems produced equal results in the oceanwater immersion test and superior performance in the accelerated salt fog/UV corrosion test.

The Corps of Engineers commonly uses a system with a phenolic aluminum topcoat on atmosphere-exposed items associated with hydraulic structures. With this type of use in mind, comparable MCU systems having MCU zinc or MIO zinc primers followed by two coats of MCU aluminum were evaluated. The two Xymax systems performed poorly, having the lowest ratings in all evaluations after 4,000 hours. The Wasser and Sherwin Williams systems with their standard zinc primers shared the top ratings after 10,000 hours. These same systems showed excellent performance in freshwater immersion, and the Wasser system had excellent performance in oceanwater immersion. These results could be beneficial for those exposed structures that are occasionally immersed due to flooding. Again, it is interesting to note that the Wasser and Sherwin Williams aluminum topcoat systems are not alone in providing excellent accelerated weathering resistance. Their systems with standard zinc primers and MIO intermediate and MIO topcoats provided performance equal to the aluminum topcoated systems. Wasser's system with standard zinc primer, MIO intermediate, and gloss topcoat actually had a higher rating after 10,000 hours. This opens the possibility of using available colors on structures in severe environments either for aesthetics or for durable safety marking.

The atmospheric test results show visible chalking on many of the systems. This level of chalk would have an obvious effect on the gloss of the coating and may have an effect on colored coatings, but was so light that there would be no measurable loss of coating thickness. It should be noted that the systems were exposed for approximately 1 year only at a latitude not noted for intense sunlight. The exposure should be continued in order to determine if the level of chalking would increase with time. It was noted in the accelerated testing that, while many of the panels developed light chalk, only the Tnemec 571 Satin Finish developed sufficient chalk to flow and somewhat obscure the corrosion in the score.

In the basic tests performed on the liquid paints (total solids, pigment, and NCO content), most of the products produced very similar test results. The test results did not appear to have any correlation with the performance noted in any of the exposure testing. The NCO test results were the only results that showed significant variation among the manufacturers and it was unclear if these data truly represent variations in the NCO content or if the variation was due to difficulties in performing the test. All products had very good spray characteristics.

Reference Standards

SSPC[*]-SP1	*Solvent Cleaning*
SSPC-SP5	*White Metal Blast Cleaning*
SSPC-SP10	*Near-White Blast Cleaning*
SSPC Paint 20	*Zinc-Rich Primers (Type I, Inorganic, and Type II, Organic)*
ASTM A36	*Standard Specification for Carbon Structural Steel*
ASTM A607	*Specification for Steel, Sheet and Strip, High Strength, Low-Alloy, Columbium or Vanadium, or Both, Hot-Rolled and Cold-Rolled*
ASTM B117	*Standard Practice for Operating Salt Spray (Fog) Apparatus*
ASTM D185	*Standard Test Methods for Coarse Particles in Pigments, Pastes, and Paints*
ASTM D521	*Standard Test Methods for Chemical Analysis of Zinc Dust (Metallic Zinc Powder)*
ASTM D523	*Standard Test Method for Specular Gloss*
ASTM D610	*Standard Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces*
ASTM D659	*Method of Evaluating Degree of Chalking of Exterior Paint Films*
ASTM D660	*Standard Test Method for Evaluating Degree of Checking of Exterior Paints*
ASTM D662	*Standard Test Method for Evaluating Degree of Erosion of Exterior Paints*
ASTM D714	*Standard Test Method for Evaluating Degree of Blistering of Paints*

[*] SSPC - Society for Protective Coatings; ASTM - American Society for Testing and Materials; FED-STD - Federal Standard.

ASTM D772	*Standard Test Method for Evaluating Degree of Flaking (Scaling) of Exterior Paints*
ASTM D1014	*Standard Practice for Conducting Exterior Exposure Tests of Paints on Steel*
ASTM D1141	*Standard Practice for Substitute Ocean Water*
ASTM D1186	*Standard Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base*
ASTM D1654	*Standard Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments*
ASTM D2244	*Standard Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates*
ASTM D2369	*Standard Test Method for Volatile Content of Coatings*
ASTM D2371	*Standard Test Method for Pigment Content of Solvent-Reducible Paints*
ASTM D3359	*Standard Test Methods for Measuring Adhesion by Tape Test*
ASTM D4214	*Standard Test Methods for Evaluating the Degree of Chalking of Exterior Paint Films*
ASTM D4141	*Standard Practice for Conducting Black Box and Solar Concentrating Exposures of Coatings*
ASTM D4417	*Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel*
ASTM D4587	*Standard Practice for Fluorescent UV-Condensation Exposures of Paint and Related Coatings*
ASTM D5894	*Standard Practice for Cyclic Salt Fog/UV Exposure of Painted Metal (Alternating Exposures in a Fog/Dry Cabinet and a UV/Condensation Cabinet)*
ASTM D661	*Standard Test Method for Evaluating Degree of Cracking of Exterior Paints*
FED-STD-141 Method 4331	*Spraying Properties*
FED-STD-141 Method 4541	*Working Properties and Appearance of Dried Film*

Appendix A: Cyclic Salt Fog/UV Test Results

Cyclic Salt Fog/UV Panels, ASTM D 4587 (average of three panels)						
	Hours of Exposure:	**2,000**	**3,000**	**4,000**	**7,000**	**10,000**
System	**Manufacturer**	**Rating #**	**Rating #**	**Rating #**	**Rating #**	**Rating #**
Zinc / Coal Tar (2 coats)	Sherwin Williams	7.00	6.00	6.00	6.00	5.00
	Tnemec	10.00*	10.00	6.60	5.00	4.60
	Wasser	9.30	7.00	7.00	6.00	6.00
	Xymax	8.30	6.00	3.60	3.00	0.00
Zinc+Acc / Coal Tar (2 coats)	Sherwin Williams	7.60	6.60	6.30	5.00	4.60
	Tnemec	10.00*	10.00	8.60	7.00	6.60
	Wasser	10.00	10.00	9.00	9.00	8.00
	Xymax	5.60	3.60	3.30	2.60	0.00
Zinc / Aluminum (2 coats)	Sherwin Williams	7.60	7.30	7.00	7.00	7.00
	Tnemec	8.00*	6.30	6.00	6.00	5.60
	Wasser	7.60	7.00	7.00	7.00	7.00
	Xymax	7.30	6.60	4.60	4.60	4.30
Zinc / MIO Intermediate / MIO Topcoat	Sherwin Williams	9.00	9.00	7.30	7.00	7.00
	Tnemec	7.30	6.60	6.00	5.00	3.00
	Wasser	9.30	9.30	7.30	7.00	7.00
	Xymax	7.30	5.60	3.60	3.60	2.60
Zinc / MIO Intermediate / Gloss topcoat	Sherwin Williams	8.60	7.00	7.00	6.60	6.00
	Tnemec	7.60	5.30	5.00	5.00	3.30
	Wasser	9.30	9.30	9.30	9.00	8.00
	Xymax	8.00	4.60	3.60	3.00	2.60
MIO Zinc / Coal Tar (2 coats)	Sherwin Williams	7.00	7.00	7.00	7.00	7.00
	Tnemec	10.00	10.00	8.30	8.00	7.30
	Wasser	6.30	6.00	4.30	4.30	4.30
	Xymax	7.60	5.00	3.30	2.60	1.30
MIO Zinc / MIO Intermediate / MIO Topcoat	Sherwin Williams	7.60	7.00	7.00	6.60	6.60
	Tnemec	7.60	6.70	6.00	6.00	4.60
	Wasser	9.00	6.30	5.30	5.30	5.00
	Xymax	7.30	5.30	3.30	3.30	3.30
MIO Zinc / MIO Intermediate /	Sherwin Williams	8.60	8.30	7.30	7.00	7.00
	Tnemec	8.30	7.00	6.60	6.30	6.30

Cyclic Salt Fog/UV Panels, ASTM D 4587 (average of three panels)						
	Hours of Exposure:	**2,000**	**3,000**	**4,000**	**7,000**	**10,000**
System	**Manufacturer**	**Rating #**	**Rating #**	**Rating #**	**Rating #**	**Rating #**
Gloss Topcoat	Wasser	7.30	6.00	4.30	4.30	4.30
	Xymax	7.30	5.30	3.60	3.00	2.00
MIO Zinc / Aluminum (2 coats)	Sherwin Williams	7.30	6.60	6.30	6.00	4.60
	Tnemec	8.30	6.60	6.60	6.00	6.00
	Wasser	6.30	6.00	6.00	5.00	4.00
	Xymax	6.60	4.00	3.60	3.30	2.60

* Topcoat delaminating from intermediate coat.

Appendix B: Oceanwater Immersion Test Results

<table>
<tr><th colspan="3">Blistering on Oceanwater Immersion Panels, ASTM D714 (two panels)</th></tr>
<tr><th colspan="2">5,000 Hours of Exposure</th><th>Comment</th></tr>
<tr><th>System</th><th>Manufacturer</th><th></th></tr>
<tr><td rowspan="8">Zinc /
Coal Tar (2 coats)</td><td rowspan="2">Sherwin Williams</td><td>Medium blistering at top of panel</td></tr>
<tr><td>Medium blistering at top of panel</td></tr>
<tr><td rowspan="2">Tnemec</td><td>Very small blistering; Topcoat delamination</td></tr>
<tr><td>Large blistering at edges; Small blistering in middle of panel; Topcoat delamination</td></tr>
<tr><td rowspan="2">Wasser</td><td>Excellent</td></tr>
<tr><td>Excellent</td></tr>
<tr><td rowspan="2">Xymax</td><td>Small blistering around scribe</td></tr>
<tr><td>Very small blistering at edges</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td rowspan="8">Zinc+Acc /
Coal Tar (2 coats)</td><td rowspan="2">Sherwin Williams</td><td>Small to Medium blistering all over</td></tr>
<tr><td>Small to Medium blistering all over</td></tr>
<tr><td rowspan="2">Tnemec</td><td>Small to medium blistering; Topcoat delamination</td></tr>
<tr><td>Medium blistering at edges; Topcoat delamination</td></tr>
<tr><td rowspan="2">Wasser</td><td>Excellent</td></tr>
<tr><td>Excellent</td></tr>
<tr><td rowspan="2">Xymax</td><td>Small blistering at edges and scribe</td></tr>
<tr><td>Small to medium blistering at edges and scribe</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td rowspan="8">Zinc /
Aluminum (2 coats)</td><td rowspan="2">Sherwin Williams</td><td>Excellent</td></tr>
<tr><td>Excellent</td></tr>
<tr><td rowspan="2">Tnemec</td><td>Excellent</td></tr>
<tr><td>Excellent</td></tr>
<tr><td rowspan="2">Wasser</td><td>Excellent</td></tr>
<tr><td>Excellent</td></tr>
<tr><td rowspan="2">Xymax</td><td>Very small to small blistering all over</td></tr>
<tr><td>Very small to small blistering all over</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

Blistering on Oceanwater Immersion Panels, ASTM D714 (two panels)		
5,000 Hours of Exposure		**Comment**
System	**Manufacturer**	
Zinc / MIO Intermediate / MIO Topcoat	Sherwin Williams	Very small blistering at edges
		Medium blistering at edges
	Tnemec	Large blistering at edges
		Excellent
	Wasser	Excellent
		Excellent
	Xymax	Small blistering at edges
		Medium blistering at edges and bottom of panel
Zinc / MIO Intermediate / Gloss topcoat	Sherwin Williams	Very small blistering on back of panel
		Excellent
	Tnemec	Excellent
		Small blistering at edges
	Wasser	Excellent
		Excellent
	Xymax	Small to medium blistering at edges and scribe
		Small to medium blistering at edges
MIO Zinc / Coal Tar (2 coats)	Sherwin Williams	Medium blistering
		Medium to large blistering
	Tnemec	Very small blistering; Topcoat delamination
		Very small blistering; Topcoat delamination
	Wasser	Excellent
		Excellent
	Xymax	Small to Medium blistering
		Medium blistering at edges
MIO Zinc / MIO Intermediate / MIO Topcoat	Sherwin Williams	Excellent
		Very small blistering
	Tnemec	Excellent
		Excellent
	Wasser	Small blistering at edges
		Very small blistering on back of panel
	Xymax	Small to Medium blistering
		Very large blistering at edges
MIO Zinc / MIO Intermediate /	Sherwin Williams	Small to Large blistering
		Large blistering on edges

Blistering on Oceanwater Immersion Panels, ASTM D714 (two panels)		
5,000 Hours of Exposure		Comment
System	Manufacturer	
Gloss Topcoat	Tnemec	Excellent
		Excellent
	Wasser	Small to medium blistering at edges
		Small to medium blistering at edges
	Xymax	Very large blistering all over
		Large blistering at edges
MIO Zinc / Aluminum (2 coats)	Sherwin Williams	Excellent
		Excellent
	Tnemec	Excellent
		Excellent
	Wasser	Small blistering at edges and bottom of panel
		Small to medium blistering at edges
	Xymax	Medium blistering at top of panel
		Medium blistering at edges

Blistering on Oceanwater Immersion Panels, ASTM D714 (two panels)							
10,000 Hours of Exposure		Panel		Scribe		Edges	
System	Manufacturer	A	B	A	B	A	B
Zinc / Coal Tar (2 coats)	Sherwin Williams	M#2	MD#2	F#1	F#4	D#1	D#1
	Tnemec	M#2*	MD#2*	10	10	M#1	D#1
	Wasser	10	10	10	10	10	10
	Xymax	F#6	F#6	F#6	F#6	F#6	F#6
Zinc+Acc / Coal Tar (2 coats)	Sherwin Williams	MD#2	MD#2	M#2	M#2	D#2	D#1
	Tnemec	D#1*	D#2*	10	10	D#1	D#1
	Wasser	10	10	10	10	10	10
	Xymax	F#7	F#6	F#3	F#4	F#2	M#3
Zinc / Aluminum (2 coats)	Sherwin Williams	10	10	10	F#5	F#1	F#1
	Tnemec	10	F#2	10	10	F#1	M#1
	Wasser	10	10	10	10	10	10
	Xymax	M#4	F#4	MD#4	M#4	MD#2	D#2
Zinc / MIO Intermediate / MIO Topcoat	Sherwin Williams	10	10	10	F#7	D#7	D#7
	Tnemec	10	10	10	10	F#2	10
	Wasser	10	10	10	10	10	10

Blistering on Oceanwater Immersion Panels, ASTM D714 (two panels)							
10,000 Hours of Exposure		Panel		Scribe		Edges	
System	Manufacturer	A	B	A	B	A	B
	Xymax	M#5	M#5	F#5	F#5	M#5	M#5
Zinc / MIO Intermediate / Gloss topcoat	Sherwin Williams	10	10	F#3	10	F#3	F#1
	Tnemec	10	10	10	10	M#6	M#2
	Wasser	10	10	10	10	10	10
	Xymax	F#3	F#3	F#4	F#4	M#3	D#2
MIO Zinc / Coal Tar (2 coats)	Sherwin Williams	MD#2	D#1	F#4	F#6	MD#2	D#1
	Tnemec	10*	10*	10	10	F#2	D#5
	Wasser	10	10	10	10	10	10
	Xymax	F#2	F#2	M#3	M#3	F#2	D#5
MIO Zinc / MIO Intermediate / MIO Topcoat	Sherwin Williams	M#7	M#7	10	10	F#1	M#1
	Tnemec	10	10	10	10	10	10
	Wasser	F#7	10	10	10	M#5	MD#4
	Xymax	MD#2	MD#2	F#4	10	M#1	D#1
MIO Zinc / MIO Intermediate / Gloss Topcoat	Sherwin Williams	MD#2	F#2	F#5	10	MD#2	F#4
	Tnemec	10	10	10	10	10	10
	Wasser	F#6	M#6	10	10	D#4	MD#4
	Xymax	MD#2	MD#2	M#4	D#3	MD#1	D#1
MIO Zinc / Aluminum (2 coats)	Sherwin Williams	10	10	10	10	10	10
	Tnemec	10	10	10	10	10	10
	Wasser	10	F#7	10	10	MD#5	M#5
	Xymax	F#1	F#1	10	F#5	F#1	MD#4

* Delamination between the mid and final coats.

Appendix C: Freshwater Immersion Test Results

Blistering on Freshwater Immersion Panels (two panels)		
5,000 Hours of Exposure		Comment*
System	Manufacturer	
Zinc / Coal Tar (2 coats)	Sherwin Williams	Large blistering in all corners
		Excellent
	Tnemec	Very small blistering
		Very small to small blistering on back of panel
	Wasser	Very small blistering
		Very small blistering
	Xymax	Small blistering at edges
		Medium blistering at edges
Zinc+Acc / Coal Tar (2 coats)	Sherwin Williams	Medium to large blistering at edges
		Medium blistering at edges
	Tnemec	Very small blistering
		Small to medium blistering at back of panel
	Wasser	Very small blistering at edges
		Very small blistering
	Xymax	Medium blistering at edges
		Excellent
Zinc / Aluminum (2 coats)	Sherwin Williams	Excellent
		Excellent
	Tnemec	Excellent
		Excellent
	Wasser	Excellent
		Excellent
	Xymax	Medium blistering at edges
		Very small blistering at edges
Zinc / MIO Intermediate /	Sherwin Williams	Excellent
		Excellent

Blistering on Freshwater Immersion Panels (two panels)		
5,000 Hours of Exposure		Comment*
System	Manufacturer	
MIO Topcoat	Tnemec	Very small blistering
		Medium blistering at top edges
	Wasser	Very small blistering at edges
		Excellent
	Xymax	Very small blistering at edges
		Small blistering at edges
Zinc / MIO Intermediate / Gloss topcoat	Sherwin Williams	Excellent
		Excellent
	Tnemec	Excellent
		Excellent
	Wasser	Very small blistering at edges
		Excellent
	Xymax	Small blistering at edges
		Rusting at bottom of scribe
MIO Zinc / Coal Tar (2 coats)	Sherwin Williams	Large blistering at edges
		Excellent
	Tnemec	Very small blistering
		Very small blistering
	Wasser	Very small blistering all over
		Very small blistering all over
	Xymax	Excellent
		Excellent
MIO Zinc / MIO Intermediate / MIO Topcoat	Sherwin Williams	Excellent
		Excellent
	Tnemec	Very small blistering at edges
		Excellent
	Wasser	Very small blistering at edges
		Medium blistering at edges
	Xymax	Very small to small blistering at edges
		Small blistering at edges
MIO Zinc / MIO Intermediate / Gloss Topcoat	Sherwin Williams	Excellent
		Excellent
	Tnemec	Excellent
		Excellent

Blistering on Freshwater Immersion Panels (two panels)		
5,000 Hours of Exposure		Comment*
System	Manufacturer	
	Wasser	Medium blistering in middle of panel; Very small blistering at edges
		Medium blistering at edges and scribe; Very small blistering in middle of panel
	Xymax	Small blistering at edges
		Medium blistering at edges
MIO Zinc / Aluminum (2 coats)	Sherwin Williams	Light undercut at scribe
		Light undercut at scribe
	Tnemec	Excellent
		Excellent
	Wasser	Excellent
		Excellent
	Xymax	Very small blistering at edges
		Excellent

* All scribes were rusting.

Blistering on Freshwater Immersion Panels, ASTM D714 (2 panels)							
10,000 Hours of Exposure		Panel		Scribe		Edges	
System	Manufacturer	A	B	A	B	A	B
Zinc / Coal Tar (2 coats)	Sherwin Williams	10	10	10	10	F#2	F#2
	Tnemec	10*	10*	F#4	10	M#2	F#4
	Wasser	10	10	10	10	10	10
	Xymax	10	10	10	F#2	F#4	10
Zinc+Acc / Coal Tar (2 coats)	Sherwin Williams	F#4	10	10	10	M#2	F#4
	Tnemec	10*	10*	MD#4	MD#4	MD#4	M#4
	Wasser	10	10	10	10	10	10
	Xymax	10	10	10	F#4	F#4	10
Zinc / Aluminum (2 coats)	Sherwin Williams	10	10	10	10	10	10
	Tnemec	10	10	10	10	10	10
	Wasser	10	10	10	10	10	10
	Xymax	10	10	10	F#4	M#2	F#4
Zinc / MIO Intermediate /	Sherwin Williams	10	10	10	10	10	10
	Tnemec	10	10	10	10	10	F#2

Blistering on Freshwater Immersion Panels, ASTM D714 (2 panels)							
10,000 Hours of Exposure		**Panel**		**Scribe**		**Edges**	
System	**Manufacturer**	**A**	**B**	**A**	**B**	**A**	**B**
MIO Topcoat	Wasser	10	10	F#4	10	F#4	10
	Xymax	10	10	10	F#4	F#4	F#4
Zinc / MIO Intermediate / Gloss topcoat	Sherwin Williams	10	10	10	10	10	10
	Tnemec	10	10	10	10	10	10
	Wasser	10	10	10	10	F#4	10
	Xymax	10	10	10	10	F#4	10
MIO Zinc / Coal Tar (2 coats)	Sherwin Williams	10	10	F#4	10	F#2	F#2
	Tnemec	MD#4*	MD#4*	M#4	M#4	MD#4	MD#4
	Wasser	10	10	F#4	10	10	10
	Xymax	10	10	F#4	F#4	F#4	10
MIO Zinc / MIO Intermediate / MIO Topcoat	Sherwin Williams	10	10	10	10	10	10
	Tnemec	10	10	10	10	10	10
	Wasser	MD#4	MD#4	MD#4	M#4	MD#2	MD#4
	Xymax	10	10	F#2	F#4	F#4	F#4
MIO Zinc / MIO Intermediate / Gloss Topcoat	Sherwin Williams	10	10	10	10	10	10
	Tnemec	10	10	10	10	10	10
	Wasser	MD#4	M#4	M#4	MD#4	MD#4	MD#2
	Xymax	10	10	10	10	F#2	M#2
MIO Zinc / Aluminum (2 coats)	Sherwin Williams	10	10	10	F#2	10	10
	Tnemec	10	10	10	10	10	10
	Wasser	10	10	10	10	10	10
	Xymax	10	10	10	10	10	10

* Delamination between the mid and final coats.

Appendix D: Atmospheric Exposure Test Results

Atmospheric Exposure Chalking (ASTM D4214 Method B)			
System	**Manufacturer**	**5,000 Hours**	**10,000 Hours**
Zinc / Coal Tar (2 coats)	Sherwin Williams	Visible	Visible
		Visible	Visible
	Tnemec	Visible *	Visible*
		Visible*	Visible*
	Wasser	Visible	Visible
		Visible	Visible
	Xymax	Visible	Visible
		Visible	Visible
Zinc+Acc / Coal Tar (2 coats)	Sherwin Williams	Visible	Visible
		Visible	Visible
	Tnemec	Visible*	Visible*
		Visible*	Visible*
	Wasser	Visible	Visible
		Visible	Visible
	Xymax	Visible	Visible
		Visible	Visible
Zinc / Aluminum (2 coats)	Sherwin Williams	None	Visible
		None	Visible
	Tnemec	None	Visible
		None	Visible
	Wasser	None	Visible
		None	Visible
	Xymax	None	Visible
		None	Visible
Zinc / MIO Intermediate /	Sherwin Williams	Visible	Visible
		Visible	Visible

Atmospheric Exposure Chalking (ASTM D4214 Method B)			
System	**Manufacturer**	**5,000 Hours**	**10,000 Hours**
MIO Topcoat	Tnemec	None	None
		None	None
	Wasser	None	None
		None	None
	Xymax	None	None
		None	None
Zinc / MIO Intermediate / Gloss topcoat	Sherwin Williams	None	None
		None	None
	Tnemec	None	Visible
		None	Visible
	Wasser	None	None
		None	None
	Xymax	None	None
		None	None
MIO Zinc / Coal Tar (2 coats)	Sherwin Williams	Visible	Visible
		Visible	Visible
	Tnemec	Visible*	Visible*
		Visible*	Visible*
	Wasser	Visible	Visible
		Visible	Visible
	Xymax	Visible	Visible
		Visible	Visible
MIO Zinc / MIO Intermediate / MIO Topcoat	Sherwin Williams	Visible	Visible
		Visible	Visible
	Tnemec	None	None
		None	None
	Wasser	None	None
		None	None
	Xymax	None	None
		None	None
MIO Zinc / MIO Intermediate / Gloss Topcoat	Sherwin Williams	None	None
		None	None
	Tnemec	None	Visible
		None	Visible
	Wasser	None	None

Atmospheric Exposure Chalking (ASTM D4214 Method B)			
System	**Manufacturer**	**5,000 Hours**	**10,000 Hours**
		None	None
	Xymax	None	None
		None	None
MIO Zinc / Aluminum (2 coats)	Sherwin Williams	None	Visible
		None	Visible
	Tnemec	None	Visible
		None	Visible
	Wasser	None	Visible
		None	Visible
	Xymax	None	Visible
		None	Visible

* Delamination between the mid and final coats.

Appendix E: Compositional Test Results

Sherwin Williams Coatings

Coating name	Total solids, % by weight of paint	Pigment, % by weight of total solids	Total zinc, % by weight of pigment	Total zinc, % by weight of total solids	NCO Content (%)
Corothane I Galvapac	92.2	91.6	94.1	86.2	6.5
Corothane I Galvapac/ accelerator	92.1	90.8	94.0	85.4	NA
Corothane I MIO Zinc	88.3	89.1	95.1	84.7	13
Corothane I Coal Tar	80.0	68.1	NA*	NA*	6.2
Corothane I MIO Aluminum	77.7	44.6	NA*	NA*	15
Corothane I Ironox B	80.3	78.4	NA*	NA*	7.6
Corothane I Ironox A	74.3	76.3	NA*	NA*	7.2
Corothane I Aliphatic HS	71.8	55.3	NA*	NA*	6

* Not applicable to this paint type.

Tnemec Coatings

Coating name	Total solids, % by weight of paint	Pigment, % by weight of total solids	Total zinc, % by weight of pigment	Total Zinc, % by weight of total solids	NCO Content (%)
90-97 MC Zinc	88.5	90.3	95.7	86.4	9
90-97 MC Zinc/ accelerator	87.3	89.7	95.3	85.5	NA
594 MIO Zinc	86.5	87.1	96.4	84.0	16
546 MC Urethane Tar	77.4	63.2	NA*	NA*	5.8
530 MC Aluminum	61.0	42.8	NA*	NA*	17
596 MIO Intermediate	79.3	72.1	NA*	NA*	6.7
571 Satin Finish	74.7	56.3	NA*	NA*	12
570 MC Hi Gloss	77.8	47.2	NA*	NA*	5.9

* Not applicable to this paint type.

Wasser Coatings

Coating name	Total solids, % by weight of paint	Pigment, % by weight of total solids	Total zinc, % by weight of pigment	Total Zinc, % by weight of total solids	NCO Content (%)
MC Zinc	89.0	89.8	94.2	84.6	9.8
MC Zinc/PUR Quik	90.0	88.4	94.1	83.2	NA
MC Mio Zinc	88.5	86.0	96.4	82.9	11
MC Tar	81.0	66.8	NA*	NA*	4.3
MC Aluminum	70.3	21.5	NA*	NA*	14
MC Ferrox B	80.7	69.8	NA*	NA*	7.8
MC Ferrox A	80.1	74.3	NA*	NA*	6
MC Luster	77.9	57.2	NA*	NA*	4.7

* Not applicable to this type of paint.

Xymax Coatings

Coating name	Total solids, % by weight of paint	Pigment, % by weight of total solids	Total zinc, % by weight of pigment	Total Zinc, % by weight of total solids	NCO Content (%)
MonoZinc MEIII	89.6	86.0	96.5	83.0	9.60
MonoZinc MEIII/ accelerator	89.8	88.0	96.0	84.5	NA
MonoZinc 390	87.6	83.5	95.7	79.9	13
MonoGuard	81.4	61.0	NA*	NA*	3.70
MonoBrite	71.2	37.7	NA*	NA*	12
MonoFerro PUR	78.3	50.3	NA*	NA*	6.10
Bridgefinish	83.1	70.6	NA*	NA*	11
MaxCoat HB	75.4	55.7	NA*	NA*	4.80

* Not applicable to this paint type.

Appendix F: Coating Thickness on Exposure Panels

Coating thickness on exposure panels (mils) (average of six panels)					
System	Manufacturer	Primer	Mid coat	Finish coat	Total System (Min-Max)
Zinc / Coal Tar (2 coats)	Sherwin Williams	3.4	6.3	7.7	16.7-17.8
	Tnemec	2.9	5.2	5.3	12.9-14.0
	Wasser	4.7	6.7	6.4	16.7-19.0
	Xymax	3.4	7.1	5.9	15.2-17.0
Zinc+Acc / Coal Tar (2 coats)	Sherwin Williams	3.3	6.0	6.4	15.2-16.1
	Tnemec	2.9	4.5	5.1	11.8-13.4
	Wasser	4.4	7.3	6.8	18.1-19.3
	Xymax	4.0	5.7	6.2	14.9-16.5
Zinc / Aluminum (2 coats)	Sherwin Williams	3.4	2.8	1.7	7.5-8.2
	Tnemec	3.0	2.2	2.2	6.8-7.7
	Wasser	4.0	1.6	1.7	6.1-7.9
	Xymax	3.3	2.1	2.2	7.0-7.9
Zinc / MIO Intermediate / MIO Topcoat	Sherwin Williams	3.3	4.1	3.6	10.5-11.6
	Tnemec	3.6	4.2	2.7	9.5-11.2
	Wasser	3.7	3.9	3.6	10.2-12.0
	Xymax	3.2	3.8	2.7	9.0-10.0
Zinc / MIO Intermediate / Gloss topcoat	Sherwin Williams	3.3	4.3	2.9	10.1-10.9
	Tnemec	3.4	4.1	2.3	9.3-10.3
	Wasser	4.3	4.4	2.9	10.7-12.0
	Xymax	3.8	3.8	3.6	10.5-11.9
MIO Zinc / Coal Tar (2 coats)	Sherwin Williams	3.4	7.6	5.7	16.2-17.5
	Tnemec	3.2	6.1	4.7	13.6-14.6
	Wasser	4.2	7.3	7.4	17.1-20.9
	Xymax	3.3	6.7	6.5	15.9-17.5

Coating thickness on exposure panels (mils) (average of six panels)					
System	**Manufacturer**	**Primer**	**Mid coat**	**Finish coat**	**Total System (Min-Max)**
MIO Zinc / MIO Intermediate / MIO Topcoat	Sherwin Williams	3.7	4.9	3.3	11.5-12.2
	Tnemec	3.2	4.4	2.6	9.4-10.6
	Wasser	4.4	4.4	3.3	11.0-13.0
	Xymax	3.8	3.8	3.1	9.2-11.4
MIO Zinc / MIO Intermediate / Gloss Topcoat	Sherwin Williams	3.5	4.7	2.6	9.8-11.6
	Tnemec	3.0	3.1	2.4	8.0-8.9
	Wasser	3.7	4.4	2.9	10.0-11.3
	Xymax	3.6	3.7	3.7	9.4-11.7
MIO Zinc / Aluminum (2 coats)	Sherwin Williams	3.6	2.8	2.0	7.5-8.9
	Tnemec	3.2	2.6	2.2	7.2-9.1
	Wasser	4.3	1.8	1.8	6.4-8.4
	Xymax	4.1	2.4	2.5	8.2-9.4

Appendix G: SSPC Paint 20 Compliance Tests

Test Procedures

Pot Life Viscosity change, 5 hours at 70 ˚F and 50% Relative Humidity (RH)

Working Properties Federal Standard (FED-STD)-141 Methods 4331 (spraying properties) and 4541 (appearance)

Mudcracking at 10X magnification

Adhesion ASTM 3359 Method B

Salt Fog Resistance ASTM B117

Coating Name	Pot life	Working Properties	Mudcracking	Adhesion	Salt Fog - 1,000 hours exposure
Sherwin Williams Galvapac	No change	No defects	No evidence of mudcracking at 7.6 mils DFT	5B	No rusting or blisters on the face of the panel, no undercutting at the scribe
Sherwin Williams Galvapac/accel	No change	No defects	No evidence of mudcracking at 6.3 mils DFT	5B	No rusting or blisters on the face of the panel, no undercutting at the scribe
Sherwin Williams MioZinc	No change	No defects	No evidence of mudcracking at 6.7 mils DFT	4B	No rusting or blisters on the face of the panel, no undercutting at the scribe
Tnemec 90-97 MCZinc	No change	No defects	No evidence of mudcracking at 6.6 mils DFT	4B	No rusting or blisters on the face of the panel, no undercutting at the scribe
Tnemec 90-97 MCZinc/accel	No change	No defects	No evidence of mudcracking at 7.4 mils DFT	4B	No rusting or blisters on the face of the panel, no undercutting at the scribe
Tnemec 594 MioZinc	No change	No defects	No evidence of mudcracking at 8.2 mils DFT	5B	No rusting or blisters on the face of the panel, no undercutting at the scribe

Coating Name	Pot life	Working Properties	Mudcracking	Adhesion	Salt Fog - 1,000 hours exposure
Wasser MC Zinc	No change	No defects	No evidence of mudcracking at 6.9 mils DFT	5B	No rusting or blisters on the face of the panel, no undercutting at the scribe
Wasser MCZinc/accel	No change	No defects	No evidence of mudcracking at 5.9 mils DFT	5B	No rusting or blisters on the face of the panel, no undercutting at the scribe
Wasser MioZinc	No change	No defects	No evidence of mudcracking at 7.0 mils DFT	4B	No rusting or blisters on the face of the panel, no undercutting at the scribe
Xymax MonoZinc MEIII	No change	No defects	No evidence of mudcracking at 5.4 mils DFT	5B	No rusting or blisters on the face of the panel, no undercutting at the scribe
Xymax MonoZinc MEIII/accel	No change	No defects	No evidence of mudcracking at 4.7 mils DFT	5B	No rusting or blisters on the face of the panel, no undercutting at the scribe
Xymax Monozinc 390	No change	No defects	No evidence of mudcracking at 6.1 mils DFT	5B	No rusting or blisters on the face of the panel, no undercutting at the scribe

Appendix H: SSPC Paint 20 Requirements

	Minimum Requirements		
Characteristics	**Inorganic**	**Organic**	**ASTM Standard**
Total Solids, % by weight of paint	78	70	D2369
Pigment, % by weight of total solids	85	83	D2371
Total zinc dust, % by weight of pigment	87	93	D521
Total zinc dust, % by weight of total solids	74	77	____

Appendix I: SSPC Draft Specification for Moisture Cure Polyurethane Topcoat

Note: This draft specification was used only as a basis for the research reported in this document. For up-to-date requirements and specifications, contact the source organization.

SSPC: The Society for Protective Coatings
PAINT SPECIFICATION NO. XMCTX
Single Component Moisture Cure Weatherable Aliphatic
Polyurethane Topcoat, Performance-Based

1. Scope
1.1 This specification covers the requirements for a high performance single component moisture cure UV-stable polyurethane topcoat (ASTM D 16, Type II polyurethane). It is intended for a topcoat that provides excellent color and gloss retention, not for thick section elastomeric coatings.
1.2 Coatings meeting the requirements of this specification are generally suitable for exposures in environmental zones 1A (interior, normally dry), 1B (exterior, normally dry), 2A (frequently wet by fresh water, excluding immersion), 2B (frequently wet by salt water, excluding immersion), 3B (chemical exposure, neutral) and 3C (chemical exposure, alkaline).
1.3 The specified coating is intended for application by brush, spray, or roller. It is generally applied over a primer or intermediate coating.

2. Description
2.1 This coating is a one-package moisture cure polyurethane coating characterized by the presence of free polyisocyanate groups capable of reacting with atmospheric moisture in order to form a film.
2.2 WEATHERING LEVELS: This specification contains three levels of accelerated and South Florida weathering performance. Table 1 specifies the amount of time the coating must perform before noticeable change in order to achieve

the defined performance level. Polyurethane topcoats are available in a wide range of color and gloss. Procurement documents shall state the desired level of performance, exposure method (in accordance with Table 1), color, and gloss. For example, a specifier may require Level 2 Florida exposure, initial gloss greater than 80, matched to a specific color. A certain level of accelerated weathering does not necessarily correspond to a particular level of atmospheric weathering and they need to be specified independently. These are two independent complementary tests for measuring coating performance. If no level is specified, Level 3 will be assumed.

Table 1. Time corresponding to each performance level.

	Accelerated UV-A Hours to noticeable change*	**Florida Exposure Months to noticeable change***
Level 1	500 to 999	12 to 23
Level 2	1000 to 1999	24 to 48
Level 3	2000 or more	48 or more

* Noticeable change is defined as a gloss loss of 30 units measured at a 60° angle (washed with a 0.1% solution of mild detergent) or a color change of greater than 2.0 DE*. (CIE 1976 L*a*b*).

3. Reference Standards

3.1 The latest issue, revision, or amendment of the referenced standards in effect at the time of the bid solicitation shall govern, unless otherwise specified. A standard marked with an asterisk (*) is referenced only in the Notes, which are not requirements of this specification.

3.2 If there is a conflict between the requirements of any of the cited reference standards and this specification, the requirements of this specification shall prevail.

3.3 SSPC Standard:

- Guide 13 Guide for the Identification and Use of Industrial Coating Materials in Computerized Product Databases

3.4. American Society for Testing and Materials (ASTM) Standards:

- D 16 Terminology Relating to Paint, Varnish, Lacquer, and Related Products
- D 523 Test Method for Specular Gloss
- D 562 Test Method for Consistency of Paints Using the Stormer Viscometer

- D 968 Test Methods for Abrasion Resistance of Organic Coatings by Falling Abrasive
- D 1014 Practice for Conducting Exterior Exposure Tests of Paints on Steel D 1259 Test Methods for Nonvolatile Content of Resin Solutions
- D 1296 Test Method for Odor of Volatile Solvents and Diluents
- D 1308 Test Method for Effect of Household Chemicals on Clear and Pigmented Organic Finishes
- D 1475 Test Method for Density of Paint, Varnish, Lacquer, and Related Products
- D 1535 Practice for Specifying Color by the Munsell System
- D 1640 Test Methods for Drying, Curing, or Film Formation of Organic Coatings at Room Temperature
- D 1849 Standard Method for Package Stability of Paint
- D 2244 Test Method for Calculation of Color Differences from Instrumentally Measured Color Coordinate
- D 2369 Test Method for Volatile Content of Coating
- D 2371 Test Method for Pigment Content of Solvent-Reducible Paints
- D 2572 Test Method for Isocyanate Groups in Urethane Materials or Prepolymers
- D 2621 Test Method for Infrared Identification of Vehicle Solids from Solvent-Reducible Paints
- D 2698 Test Method for the Determination of Pigment Content of Solvent-Reducible Paints by High Speed Centrifuging
- D 2794 Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)
- D 3359 Test Methods for Measuring Adhesion by Tape Test
- D 3719 Test Method for Quantifying Dirt Collection on Coated Exterior Panels
- D 3925 Practice for Sampling Liquid Paints and Related Pigmented Coatings
- D 4214 Test Methods for Evaluating Degree of Chalking of Exterior Paint Film
- D 4587 Practice for Conducting Tests on Paint and Related Coatings and Materials Using a Fluorescent UV-Condensation Light- and Water-Exposure Apparatus
- D 5402 Practice for Assessing the Solvent Resistance of Organic Coatings Using Solvent Rubs
- D 5590 Test Method for Determining the Resistance of Paint Films and Related Coatings to Fungal Defacement by Accelerated Four-Week Agar Plate Assay

3.5 **American National Standards Institute (ANSI) Standard:**

- Z129.1 Hazardous Industrial Chemicals – Precautionary Labeling

3.6 Federal Specifications and Standards:

- FED-STD-141 Paint, Varnish, Lacquer and Related Materials: Methods of Inspection, Sampling and Testing
  — Method 3011 Condition in Container
  — Method 4321 Brushing Properties
  — Method 4331 Spraying Properties
  — Method 4541 Working Properties and Appearance of Dried Film

4. Composition Requirements

4.1 The manufacturer is given wide latitude in the selection of raw materials and manufacturing processes. (See Note 11.1.)

4.2 RESIN REQUIREMENT: In order to ensure sufficient crosslinking and maintain the integrity of moisture-cure systems, a minimum of 3.5% isocyanate content of the vehicle solids will be required. See Annex 1 for the experimental method.

5. Requirements of Liquid Coating

5.1 PACKAGE STABILITY: Package stability shall be tested in accordance with ASTM D 1849. Storage conditions shall be 30 days at 52 ± 1°C (125 ± 2 °F). A change in consistency of greater than 10 Krebs units or noncompliance with the application requirements shall be cause for rejection.

5.2 APPLICATION PROPERTIES: All guidance provided by the manufacturer regarding mixing of multi-component products, thinning requirements, induction times, and special application requirements shall be followed. The coating shall be easily applied by brush, roller, or spray when tested in accordance with FED-STD-141, Methods 4321, 4331, and 4541. The paint shall show no streaking, running, or sagging during application or while drying.

6. Weathering Requirements

6.1 WEATHERING RESISTANCE: Two weathering test procedures are specified below. Test data may not be available for the desired color and gloss specified. Performance levels are established using whites and light colors. It is left to the discretion of the specifier whether to accept Florida data from a similar color or to use UV-A data in lieu of Florida weathering data.

6.1.1 **Accelerated Weathering:** Accelerated weathering shall be performed in accordance with ASTM D 4587, Procedure B. Test panels shall have a primer/intermediate coat as recommended by the manufacturer.

6.1.2 **South Florida Weathering:** South Florida weathering shall be performed in accordance with ASTM D 1014 (45 degrees south exposure, washed with mild detergent.) Test panels shall have a primer/intermediate coat as recommended by the manufacturer.

6.1.3 Application shall be according to manufacturer's recommendations. A minimum of 3 panels shall be exposed. Clear coatings must be tested over the intended basecoat. 60 degree gloss shall be measured according to ASTM D 523 and tristimulus color measured according to ASTM D2244 both initially and at the end of each level period. A change from initial gloss of less than 30 units or a change from initial color of less than 2.0 DE* (CIE 1976 L*a*b*) shall be required to meet the Level as indicated in Table 2 below. Table 2 summarizes the tests of Section 6 as well as the minimum acceptance criteria.

Table 2. Summary of performance testing results to be reported.

Exposure Test	Performance Level	Exposure Time	Measurement Test/Minimum Criteria	
			Color Change ASTM D 2244	**Gloss Loss ASTM D 523**
Accelerated Weathering ASTM D4587	Level 1	500 h	Color Change less than 2.0 ΔE^*	Gloss Loss less than 30
	Level 2	1000 h		
	Level 3	2000 h		
South Florida Weathering ASTM D1014	Level 1	12 mo	Color Change less than 2.0 ΔE^*	Gloss Loss less than 30
	Level 2	24 mo		
	Level 3	48 m		

7. Material Quality Assurance

If the user chooses, tests may be used to determine the acceptability of a lot or batch of a qualified coating. (See Note 11.2.)

8. Labeling

8.1 Labeling shall conform to ANSI Z129.1

8.2 Technical data shall be provided for at least all data elements categorized as "essential" in SSPC-Guide 13.

9. Inspection

9.1 All coatings supplied under this specification are subject to timely inspection by the purchaser or his authorized representative. The contractor shall replace such material as is found defective under this specification. (See Note 11.3.) In case of dispute, unless otherwise specified, the arbitration or settlement procedure established in the procurement documents shall be followed. If no arbitration procedure is established, the procedure specified by the American Arbitration Association shall be used.

9.2 Samples of paints may be requested by the purchaser and shall be supplied upon request along with the manufacturer's name and identification for the materials. Samples may be requested at the time the purchase order is placed, at pre-shipment, or may be taken from unopened containers at the job site.

9.3 Unless otherwise specified, the sampling shall be in accordance with ASTM D 3925.

10. Disclaimer

10.1 While every precaution is taken to ensure that all information furnished in SSPC standards and specifications is as accurate, complete, and useful as possible, SSPC cannot assume responsibility nor incur any obligation resulting from the use of any materials, coatings, or methods specified herein, or of the specification or standard itself.

10.2 This specification does not attempt to address problems concerning safety associated with its use. The user of this specification, as well as the user of all products or practices described herein, is responsible for instituting appropriate health and safety practices and for insuring compliance with all governmental regulations.

11. Notes

Notes are not requirements of this specification.

11.1 VOC CONTENT: Each coating, after recommended thinning, must conform to published government regulations regarding volatile organic compound (VOC) content. VOC information should be supplied on the label or the technical data sheet. Various governmental agencies may have different VOC limits or use different methods of testing. The owner may modify this specification as necessary to specify a particular VOC content limit consistent with local regulations. Coatings meeting the composition and performance requirements of this specification usually have a VOC level between 0 and 450g/L (0 and 3.75 lb/gal)

11.2 QUALITY ASSURANCE TESTS: The quality assurance tests are used to determine whether the supplied products are of the same type and quality as those originally tested and certified for acceptance. The selected tests should accurately and rapidly measure the physical and chemical characteristics of the coating necessary to verify that the supplied material is substantially the same as the previously accepted material. All of the quality assurance tests must be performed on the originally submitted qualification sample. The results of these tests are used to establish pass/fail criteria for quality assurance testing of supplied products.

11.2.1 **Establishing Quality Assurance Acceptance Criteria:** Many ASTM test methods contain precision and bias statements. Specification developers should be cognizant of the fact that these statements exist. Quality assurance test criteria should not be more stringent than the interlaboratory precision of the test methods used.

Example: A common quality assurance test is density (weight per gallon) as measured by ASTM D 1475. The interlaboratory reproducibility at the 95% confidence level tells us that any two measurements that differ by more than 1.8% should be considered suspect. This only represents the precision of the measurement technique and does not account for normal variances in the manufactured product.

The acceptable range for paint density must be stated. For example, a composition specification may state this requirement as 10.0 ± 0.2 lb/gal, 10.0 lb/gal ± 2%, or as a range from 9.8 to 10.2 lb/gal. The manufacturer of proprietary products should provide this information. Using these values, if the manufacturer's lab measures the density to be 9.8 lb/gal, the product meets the specification and the paint is shipped to the job. Because of the lab-to-lab variation of 1.8%, the user's lab may measure the density of this sample to be as low as 9.8 less 1.8% of 9.8 (= 9.6 lb/gal). Similarly for the high end, the manufacturer may measure density of 10.2 lb/gal while the user measures 10.2 + 1.8% (= 10.4 lb/gal). The pass/fail criteria for the user to accept a batch of paint should therefore be 9.6 to 10.4 lb/gal. Where precision and bias data are not available for a given test method, determine the standard deviation of a minimum of five measurements taken on the originally tested and certified material. The pass/fail criterion is that the measurement of the test sample shall fall within two standard deviations of the target value. The contracting parties must agree on a target value.

11.2.2 **Quality Assurance Tests:** Quality assurance tests include but are not limited to: infrared analysis (ASTM D 2621), viscosity (ASTM D 562), weight per gallon (ASTM D 1475), total solids (ASTM D 2369), dry time (ASTM D 1640), percent pigment (ASTM D 2371), gloss (ASTM D 523), color (ASTM D 1535), condition in container (FED-STD-141, Method 3011), and odor (ASTM D 1296).

11.3 The procurement documents should establish the responsibility for samples, testing, and any required affidavit certifying full compliance with the specification.

ANNEX

1. Theoretical Calculation for Percent Polyisocyanate by Weight in the Total Vehicle

This example is for the formulator who knows the composition of the coating. Consider just the resin component for this calculation.

	Weight	Weight Solids
Polyol A	100.00	70.00
Aliphatic Polyisocyanate B	30.00	27.00
	130.00	97.00

Fraction (Percent) of polyisocyanate in total vehicle = 27 ÷ 97 = 0.278 or 27.8% by weight.

2. Method for Determination of Percent Polyisocyanate in the Total Vehicle Solids

Part 1 In order to test a one-component topcoat for %NCO, the resin system must first be separated from the paint. This is done by placing a 25g sample of the paint into a high-speed centrifuge tube and centrifuging at 5000 to 6000 rpm until the pigment and resin have completely separated. Thinning with urethane grade Xylene may be necessary to completely separate the pigment and resin.

Part 2 Determine the percent non-volatile vehicle content by weight of the supernatant (clear centrifugal liquid) by ASTM D 1259.

Part 3 Determine the weight percent isocyanate of the supernatant by ASTM 2D2572.

Part 4 Calculate the Weight Percent Isocyanate by dividing the isocyanate content (Step 3) by the percent non-volatile (Step 2).

Appendix 1: Optional Laboratory Physical Tests of Applied Films

Typical properties that might be expected of a quality polyurethane topcoat are described below with corresponding ASTM test methods and suggested test requirements.

Test	ASTM	Result (Units)	Typical Values
Adhesion	D 3359	— — —	4B or better
Direct impact resistance	D 2794	inch-lb	30 inch-lb or greater
Abrasion resistance (falling sand)	D 968	liters/mil	15 liters/mil or greater
Solvent (MEK) resistance	D 5402	no. of double rubs	50-150 DR for MEK
Accelerated fungal resistance fig-	D 5590	disfigurement rating	5-10 where 10 is no dis- urement
Quantifying dirt collection rior	D 3719	photographic standard	DE*< 2.0 on coated exte- panels
Evaluating degree of ing chalking of exterior paints	D 4214	photographic standard rating method	6-8 where 10 is no chalk-
Effect of household chemicals on clear and pigmented organic finishes	D 1308	-----	No visual effects

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14. ABSTRACT

The Corps of Engineers is considering the use of moisture cure urethane paints on navigation and other hydraulic structures. Since it is desirable to specify paints generically, work was initiated to determine the salient properties of commercially available products from four manufacturers. Testing included short-term bench tests on the liquid materials as well as long-term exposure testing of coated panels in sea salt immersion, freshwater immersion, atmospheric exposure, and accelerated weathering conditions. The results showed significant performance differences among similar products from alternate manufacturers.

15. SUBJECT TERMS
High Performance Materials and Systems (HPM&S) Research Program; paint; resin; coatings; moisture cure urethane (MCU)

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